

# Design of Thermal Control Subsystem for TUSAT Telecommunication Satellite

N. Sozbir, M. Bulut, M.F.Oktem, A.Kahriman and A. Chaix

**Abstract**—TUSAT is a prospective Turkish Communication Satellite designed for providing mainly data communication and broadcasting services through Ku-Band and C-Band channels. Thermal control is a vital issue in satellite design process. Therefore, all satellite subsystems and equipments should be maintained in the desired temperature range from launch to end of maneuvering life. The main function of the thermal control is to keep the equipments and the satellite structures in a given temperature range for various phases and operating modes of spacecraft during its lifetime. This paper describes the thermal control design which uses passive and active thermal control concepts. The active thermal control is based on heaters regulated by software via thermistors. Alternatively passive thermal control composes of heat pipes, multilayer insulation (MLI) blankets, radiators, paints and surface finishes maintaining temperature level of the overall carrier components within an acceptable value. Thermal control design is supported by thermal analysis using thermal mathematical models (TMM).

**Keywords**—Spacecraft thermal control, design of thermal control.

## I. INTRODUCTION

TUSAT Thermal Control Subsystem (TCS) consists of active and passive control elements to maintain the spacecraft components and structures within a controlled temperature range during all the mission phases. The payload equipments and their operational requirements are considered as a main drive for developing TUSAT thermal control design, and analysis. The GEO satellite, TUSAT, has a maneuver lifetime of at least 16 years and an operational lifetime of at least 15 years in its nominal location. TUSAT has a three-axis stabilized type satellite platform that is supported with communication module (CM) and service module (SM).

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TUSAT payload configuration provides 16 active Ku band channels and 4 active C band channels. Redundancy is. There are three distinct coverage areas named as East, West and provided by 4 Ku-band and 1 C-band redundant transponders Turkey coverage. East and West coverages are Ku-Band and both have capability of transmitting and receiving. Ku and C bands have Turkey coverage. Ku band Turkey coverage is transmit only, but C band Turkey coverage is both receive and transmit.

In addition to this, Ku-Band Turkey transmits coverage and C-Band Turkey coverage for transmit and receive are available.

The antenna subsystem consists of two main shaped antenna reflectors deployed on the east and west sides of the spacecraft and two Gregorian antennas located on the earth deck.

Main features of the satellite are:

- Orbital location: 42° E
- Communication capacity: Ku band 16 channels (redundancy:20/16), C band 4 channels (redundancy:6/4)
- Propulsion needed for 15 years: 1550 kg
- Satellite nominal dry mass: 1150 kg
- Overall dimensions of the main body: 2200 x 2000 x 2825 mm
- Solar array wingspan: 14564.5 mm
- Payload Consumption (EOL): 3628 W
- Satellite Power Consumption (EQ-EOL): 4828 W
- Satellite Solar Array Power (EQ-EOL): 5606 W
- Reliability (15 years): 0.90
- Launch vehicle compatibility: Ariane V, Atlas V, Delta IV, Sea/Land Launch, Proton, Long March

## II. SPACECRAFT SYSTEM THERMAL DESIGN

TUSAT satellite is divided into two functional subsystems which are payload and platform units. The payload unit consists of repeater, antennas, and telemetry, command & ranging subsystem (TCR) to ensure the communication mission. The platform unit consists of avionics, unified propulsion subsystem (UPS), electric power subsystem (EPS), structural subsystem, mission- control subsystem (AOCS) and thermal control subsystem to ensure the mission control and stability.

The dissipative payload equipments are located on North and South panels and installed on main heat-pipe networks using thermal fillers to improve the thermal contact between units and heat-pipes. The heat-pipe networks are subdivided in

separate networks according to various qualification temperature levels.

External surfaces of North and South panels are covered by optical solar reflector (OSR). The radiative areas of these panels are sized to radiate the maximum heat dissipation generated by 16 Ku-band and 4 C-band channels fully operating. Heaters are implemented to compensate the payload dissipation variation versus repeater operational modes.

The structure subsystem provides housing for payload and platform equipments. The subsystem is designed to withstand the natural environmental forces for all static and dynamic loads encountered during ground handling, transportation, ground test, and launch phases. This subsystem is mainly made of carbon fiber reinforced plastics (CFRP). Structure elements of sandwich panels are made of aluminum honeycomb core material and carbon fiber skins. However, north/south panels are made of aluminum skins due to thermal constraints.

The propulsion subsystem is bi-propellant and has unified propulsion system (UPS). Multi layer insulation (MLI) or low emitting coating is used around propellant tanks and lines. Dedicated heaters are used on propellant tanks, UPS lines, 10 N thrusters, and 400 N apogee engine to ensure minimal required temperatures, High temperature protections and heat shields around thrusters are also applied to protect the satellite from heat flux and plume impingement during firing.

The platform equipments are located on the lower side of north and south service module (SM) panels. Batteries (Li-Ion), power conditioning unit (PCU), and payload platform distribution unit (PLFDIU) are mounted and located on N/S SM panels. Internally, batteries are decoupled radiatively from the spacecraft body with MLI blankets. Dedicated radiative areas are designed to reject the heat dissipation. Battery design concept includes thermal filler at base plate mounting interface. Nominal and redundant heaters are used to maintain batteries at minimum temperatures.

The solar array subsystem generates the necessary power for full operation of the satellite during sunlight and battery charging for eclipse. Two solar array wings are fixed on the North and South faces of the body.

Two star trackers (STR) and two sun sensors are fixed on SM, earth panel, and anti-earth panel respectively. Dedicated thermal design is required for these optical sensors. Radiative areas and heaters are utilized. Due to particular exposure to space and sun, MLI blankets are used to insulate the unit except the optical active sensor and radiative areas.

The communication mission is achieved by payload antennas. Two Gregorian antennas (also called reflectors) are mounted on the earth panel and two deployable antennas are hinged on the east and west panels. . In addition, two sets of omni antennas are used for telemetry, command and ranging purposes. Antennas are thermally insulated from spacecraft structure. The deployment mechanism interface with the spacecraft is insulated by thermal washers. Dedicated control heaters are installed on the heat pipe networks near equipments.

Two types of optical sensors are used for attitude determination and control. These sensors are the star trackers and coarse sun sensor. The star trackers (STR) and the sun sensor are fixed on upper earth panel of the SM and on the anti-earth panel respectively. For these optical sensors, a dedicated thermal design is required and radiative areas and heaters are needed.

### III. ACTIVE AND PASSIVE THERMAL CONTROL HARDWARE

The idea of the satellite thermal design is constructed on keeping all its components within their specified temperature range. The common design approach is to use a combination of MLI blankets, OSR, heat pipes, heaters, surface finishes, paints and thermistors [1, 2, 3,4, 5,6 and 7].

TUSAT thermal control uses North and South panels to reject the internal heat dissipation and limits the diurnal variation because of the minimal solar illumination on these faces. The radiative areas are covered with optical solar reflector (OSR). The OSR keeps the most stable optical thermal properties in space and is used in spaces where a surface finish with a low value of solar absorptive  $\alpha$  and a high infrared emissive  $\epsilon$  is needed. Typical thermo-optical characteristics are  $\alpha$  (BOL) = 0.11,  $\alpha$  (EOL) = 0.27 and  $\epsilon=0.84$ . The sizing of the radiative areas are defined by taking into account the worst conditions of maximum heat dissipation, maximum solar illumination (solstices), end-of-

TABLE 1 OSR RADIATIVE AREAS

|                         |           | North Panel (m <sup>2</sup> ) | South Panel (m <sup>2</sup> ) | Total (m <sup>2</sup> ) |
|-------------------------|-----------|-------------------------------|-------------------------------|-------------------------|
| CM                      |           | 3.29                          | 3.56                          | 6.85                    |
| SM                      | Batteries | 0.11                          | 0.11                          | 0.22                    |
|                         | SM Units  | 0.81                          | 0.81                          | 1.62                    |
| Total (m <sup>2</sup> ) |           | 4.21                          | 4.48                          | 8.69                    |

life thermo-optical properties. TUSAT radiative areas are summarized in Table 1.

The satellite body is isolated from the space environment by MLI blankets wrapping the body.. Multilayer insulation (MLI) is externally used on the satellite body except north/south radiative areas as well as surfaces that has to be free of MLI in order to minimize the heat input from solar radiation or the heat leakage. MLI is also used on internal parts of satellite for avoiding excessive heating of components located on the internal structure or around the batteries and propulsion components to emphasize heating efficiency by reducing heat leakage. Another application area of MLI is isolating high temperature radiative areas from internal units [3, 4 and 5].

Natural surface finishes are used under the insulation blankets for all graphite epoxy structures. Dissipative units are

black painted and black paint is used on the inner surfaces of the north and south panels. Thermal coating is not applied to equipment units with low or zero dissipation if these equipments are provided with a low emissivity.

The high dissipative units of communication and service modules are located on constant conductance heat pipes (CCHP) assembled in specific networks dedicated to radiator panels. The heat pipes are installed on the inner surface of the north/south panels. The main heat pipes, directly contact with the high dissipative units, are connected by crossing heat pipes to spread the heat dissipation over the whole heat pipe networks. CCHP are used to remove highly concentrated heat dissipation from repeater units such as traveling waveguide tube (TWT), output multiplexer (OMUX), electrical power conditioner (EPC), power conditioning unit (PCU) and payload platform distribution unit (PLFDIU). Dissipative units are mounted on CCHP using thermal filler to ensure efficient thermal transfer between units and heat pipes. Heat pipes are subdivided into separate networks according to various defined temperature levels. Heat pipe layout has been designed such a way that it prevents the failure of any heat pipe without consequent degradation of satellite performance.

Heaters and thermistors are the active thermal control subsystem parts. TUSAT thermal control utilizes heaters to provide temperature control during nominal operation phases of several platform equipments such as optical sensors, thrusters, batteries. Controlling payload equipments by compensating its power dissipation variation according to the operating modes and the effects of seasonal sun exposure is another task for thermal control applications. Active thermal regulation is achieved by the software implemented in the central data management unit (CDMU) which controls automatically ON/OFF heater switching. Temperature levels provided by thermistors are compared with predefined temperature limits. Heater regulation, thermal control and monitoring of dissipative units are performed by thermistors [6 and 7].

#### IV. DESIGN VERIFICATION BY THERMAL ANALYSIS

TUSAT thermal analysis is related with satellite temperature predictions in apparent or assumed heating environment. Thermal control subsystem (TCS) at preliminary design review (PDR) level aims validation of sufficient radiative surfaces which have the main function of keeping equipment temperatures below their high operational limits. Confirmation of available heating power budget which is sufficient to maintain equipments within their operational temperature limits regarding to the payload drive level is accomplished. Solar fluxes, satellite lifetime and satellite operational configuration are taken into account in worst case analyses. Solar flux has also considered for winter solstice, summer solstice and equinox conditions. Satellite operational lifetime is 15 years. Satellite operational configuration is arranged according to number and location of channels, ON/OFF conditions, repeater operation levels from no drive to

full drive.

Satellite thermal design is based on the analysis of critical cases that exposes the equipment to extreme thermal conditions. Two critical cases are identified from the external environment point of view, These critical cases are hot case and cold case.

Hot and cold case analyses are adopted to define upper and lower bounds on predicted temperatures. They are carried out for CM, SM, and external equipments in different conditions. The power profile for a hot case analysis corresponds to an operation in which components' activity results in high dissipation, while the orbit is in such a situation that the radiators are exposed to considerable solar fluxes.

Overall spacecraft Thermal Mathematical Model (TMM) using ThermXL which is Alstom thermal software is established since the beginning of the program and has continuously been updated. Each modification of the satellite thermal model introduced in the TMM is justified, monitored and recorded according to the TMM evolution. A complete set of analysis cases covering main payload operational combinations and all seasonal and mission conditions are performed to demonstrate overall thermal compliance. Main payload equipment temperature predictions resulting from PDR analysis are shown in Table for geostationary orbit position. Thermal analysis at EOL accounted for a degraded value of OSR absorption is equal to 0.27.

#### V. PROJECT STATUS

TUSAT will be the first indigenous Turkish Communication Satellite and is designed by a group of Turkish engineers. Presently, TUSAT is at PDR level and it is expected to be ready for critical design review (CDR) in the next two years and launched in 2015.

The aims of the thermal analyses are to size the radiative areas and heating budget at PDR phase. In order to maintain unit temperature (hot and cold cases) within non-operating and operating temperature ranges, heating budget needs to be determined.

Active and passive thermal control elements are provided to control the TUSAT temperature. Thermal control system and mathematical thermal model are presented. The TCS used in the spacecraft is designed to control temperature variations throughout the spacecraft mission lifetime.

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TABLE II PAYLOAD EQUIPMENT TEMPERATURE PREDICTIONS IN GEO PHASE

| Module   | Units | Qualif. Temp. |           | Extreme Calc. Temp. |           |
|----------|-------|---------------|-----------|---------------------|-----------|
|          |       | Tmin (°C)     | Tmax (°C) | Tmin (°C)           | Tmax (°C) |
| North CM | EPC   | -15           | 65        | -7.16               | 39.24     |
|          | CAMP  | -15           | 65        | -6.87               | 39.2      |
|          | TWT   | -15           | 85        | 12.0<br>3           | 52.94     |
|          | OMUX  | 10            | 80        | 12.0<br>3           | 52.94     |
|          | TCR   | -30           | 65        | 3.05                | 33.79     |
| South CM | EPC   | -15           | 65        | -7.01               | 37.83     |
|          | CAMP  | -15           | 65        | -6.49               | 37.78     |
|          | TWT   | -15           | 85        | 8.82                | 51.63     |
|          | OMUX  | 10            | 80        | 8.82                | 51.63     |
|          | Rx    | -30           | 65        | -0.18               | 35.02     |